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Deterioration of mechanical characteristics of micro-cantilevers by plasma induced damage

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1. Introduction

Microelectromechanical systems (MEMSs) are the integrated microsystems of mechanical elements, sensors, actuators, and electronics on a common silicon substrate. Significant processes for this integration are based on an integrated circuit (IC) technology, such as thin film deposition and etching. Therefore, it is unavoidable to use plasma process.[1] However, the plasma process usually causes the defects to the micro structure due to the high-energy ion bombardment, charge build-up and UV photon radiation from the plasma.[2] Given these factors, the plasma radiation might deteriorate the mechanical characteristics of the micro elements, such as micro cantilever, and result in MEMS malfunction.

In this study, we evaluated the damage to the mechanical characteristic of micro cantilever by conventional plasma irradiation. We also proposed a new process using neutral beam (NB)[3,4] to effectively reduce the damage on the micro element.

2. Experimental

As shown in Figure 1(a)-(i), a SOI (silicon on insulator), composed of a 0.2μm-thick top Si layer, a 0.4μm-thick buried SiO_2 layer and 300μm-thick Si substrate, was used to fabricate the micro Si micro cantilever. The fabrication process started with (ii) the patterning of top Si layer by photolithography and fast atom beam etching; (iii) Si substrate was completely etched by deep reactive-ion etching (RIE) as known as Bosch process, (iv) the buried SiO_2 was removed by HF. Figure 1(b) shows a schematic diagram of Si micro cantilever.

After the fabrication, the micro cantilevers were irradiated by inductively coupled plasma (ICP) and NB with argon (Ar) gas at room temperature. The ICP was generated by RF generator with power of 1000W and frequency of 13.56MHz. The flow was 30sccm with working pressure of 30 mtorr. The NB system, as shown in Figure 2, consists of plasma and process chambers, which are separated by a carbon aperture. This aperture can effectively eliminate irradiation of charged particles and UV photons from the plasma when the plasma passes through it from the plasma chamber to the process chamber. Pulse-time modulated RF power with ON/OFF ratio of 50μs/50μs was used in the plasma chamber and the irradiation conditions, including power, frequency, flow rate, of NB were the same as those of ICP.

In order to evaluate the influence of the irradiation of ICP and NB, the Q factor and resonant frequency (f) of micro cantilever were measured using a laser Doppler vibrometer before and after irradiation.

3. Results and discussions

Figure 3 shows the Q factor of micro cantilevers after plasma and NB irradiations with 1 minute. The Q factor of micro cantilevers drastically decreased after plasma irradiation. On the contrary, the Q factor of micro cantilevers after NB irradiation almost kept the same as before. The result indicates that the plasma irradiation induce the defects in the micro cantilever, which deteriorates the mechanical property of it. We also investigated the irradiation time dependence of the Q factor and f using plasma and NB irradiations. Figure 4 shows the Q factor ratio (Q factor ratio: Q factor after irradiation/Q factor before irradiation) and the f ratio (f ratio: f after irradiation/f before irradiation) after plasma and NB irradiations. As shown in Figure 4(a), the Q factor ratio only slightly decreased as the

NB irradiation time increased. However, the Q factor ratio did not depend on the irradiation time. This might be that the impact of defect generation on Q factor was already saturated within 1 minute. As shown in Figure 4(a), the f ratio was independent of NB irradiation time; however, the f ratio decreased as the plasma irradiation time increased. These results suggested that the plasma irradiation indeed deteriorates the mechanical characteristics of micro cantilever and the deteriorations could be drastically reduced using damage-free NB irradiation. Detailed mechanism for the mechanical characteristics deterioration of micro cantilevers will be investigated in the near future.

4. Conclusions

Mechanical characteristics, including Q factor and f, of micro cantilever were evaluated after plasma and NB irradiation using laser Doppler vibrometer. Both Q factor and resonance frequency were decreased by plasma irradiation. It revealed that plasma irradiation induces the damage to the micro element. On the other hand, in the case of NB irradiation, both characteristics almost did not change after irradiation, which indicates that the NB process is an damage-free process. Therefore, NB process may have great potential to play an important role in the micro fabrication processes.

References

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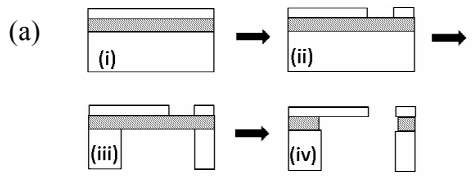


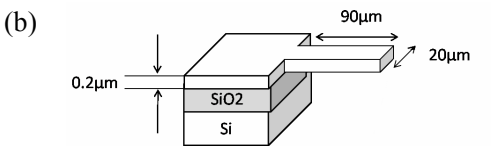


Figure 1. (a) Fabrication process and (b) schematic diagram of micro cantilever

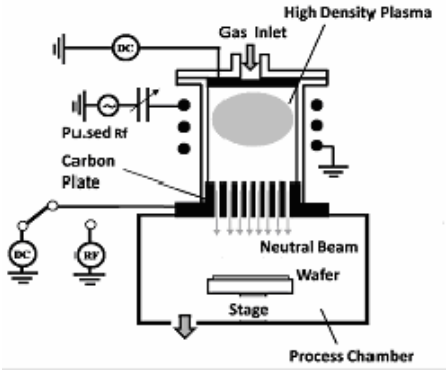


Figure 2. Neutral Beam apparatus

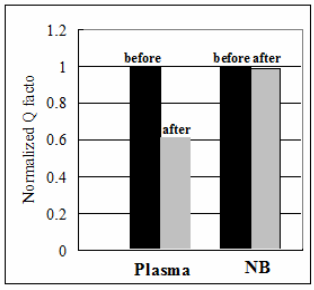
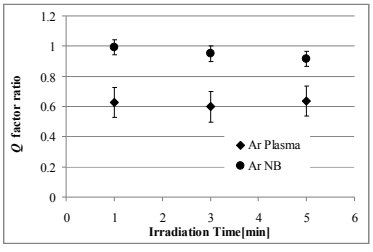
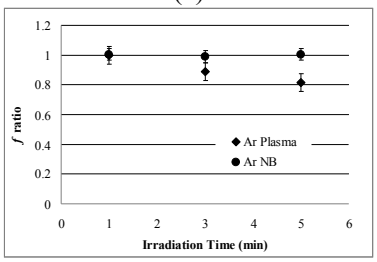


Figure 3. Q factor of micro-cantilever with or without (a) Plasma/(b) Neutral Beam irradiation



(a)



(b)

Figure 4. Irradiation time dependence of (a) Q factor ratio and (b) f ratio for micro cantilever using plasma and NB irradiations.